Ambient Groundwater Quality of the Willcox Basin: An ADEQ 1999 Baseline Study

I. Introduction

The Willcox Groundwater Basin (WGB), located in southeastern Arizona (**Figure 1**), is composed of a broad alluvial valley with a pork-chop shaped playa at its center and rugged mountain ranges at its fringes. This WGB factsheet is based on a regional groundwater quality study conducted in 1999 by the Arizona Department of Environmental Quality (ADEQ)[1].

II. Background

The WGB comprises 1,911 square miles in the northern part of the Sulphur Springs Valley. The basin is roughly 90 miles long and varies from 10 to 30 miles wide. Its boundaries include the Pinaleno Mountains to the northeast, the Dos Cabezas and Chiricahua Mountains to the east, the Pedregosa and Swisshelm Mountains and Squaretop Hills to the south, and the Dragoon, Little Dragoon, Winchester, and Galiuro Mountains to the west (**Figure 1**). The mountain ranges on the basin's east side are higher than those on the west. The WGB is predominantly a closed basin where surface water drains into the Willcox Playa at the center of the basin. The playa, where floodwaters collect before evaporating, is mostly bare and covers 50 square miles (**Figure 2**).

Principal landowners in the WGB include private entities, the State of Arizona, and the U.S. Forest Service.

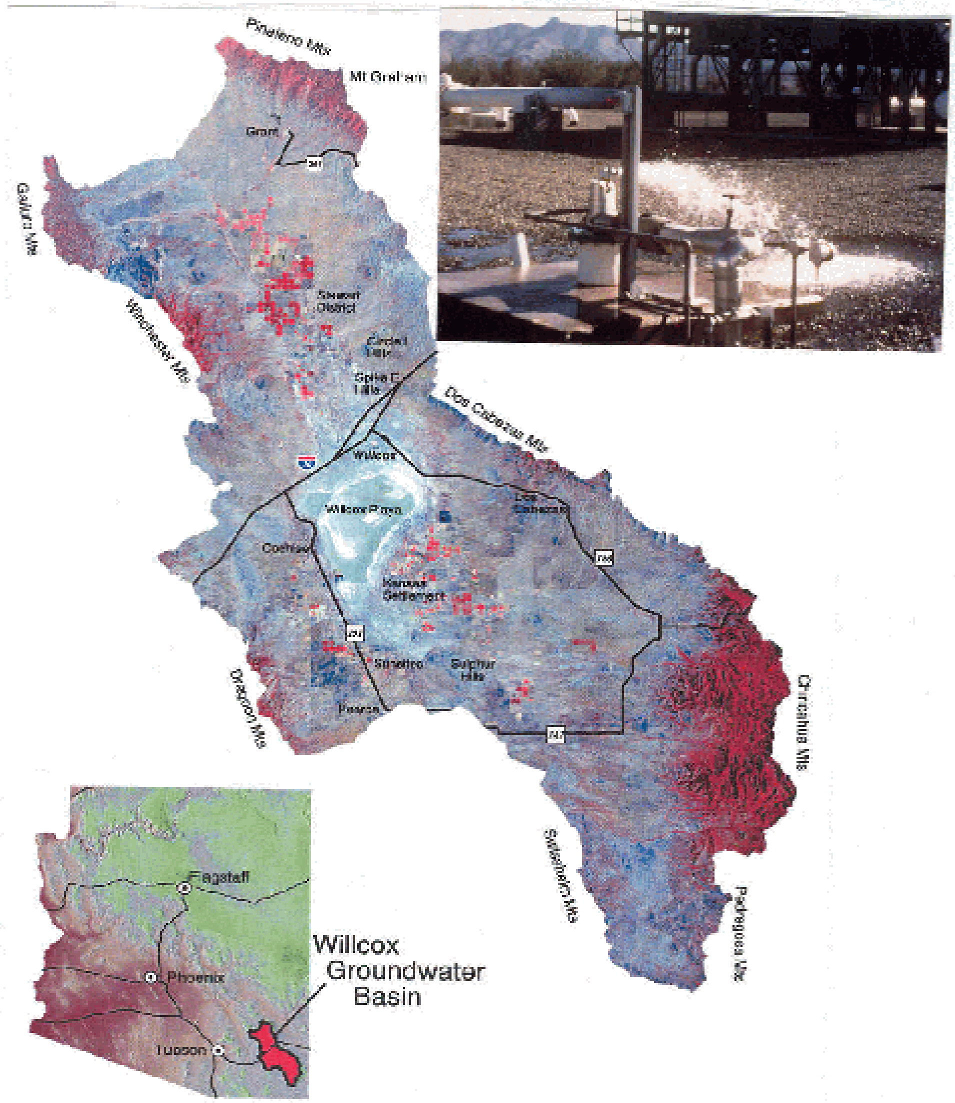

Figure 1. Infrared satellite image (June 1993) of the Willcox Groundwater Basin (WGB). Irrigated farmland is shown in bright red, mountain forests in dull red, shrub/grasslands in blue, and the Willcox Playa is in white. Inset map shows the location of the WGB within Arizona. Inset photo shows a pumping industrial well with the Dos Cabezas Mountains in the background.

Figure 2. To the south, the Sulphur Hills rise above the stark expanse of the Willcox Playa.

Willcox is the largest city in the basin while Cochise, Kansas Settlement, Pearce, and Sunsites are smaller communities. Major agricultural areas include the Stewart District north of the playa and the Kansas Settlement District southeast of the playa (**Figure 1**).

III. Hydrology

This study examined the water quality of the *alluvial aquifer* and *hardrock* areas. The *alluvial aquifer* is the WGB's principal water-bearing unit and is composed of unconsolidated stream and lacustrine alluvial deposits. At greater depths, the alluvial deposits are partially consolidated with low-to-moderate permeability. Stream deposits are the most productive alluvium, but may be thin and separated by impermeable silt and clay lenses[2]. Irrigation wells in the Stewart District typically tap stream deposits while those near Kansas Settlement usually pump

> ***"Groundwater in much of the WGB, particularly in alluvial areas not in close proximity to the Willcox Playa and the Sulphur Hills, appears to be largely suitable for domestic use."***

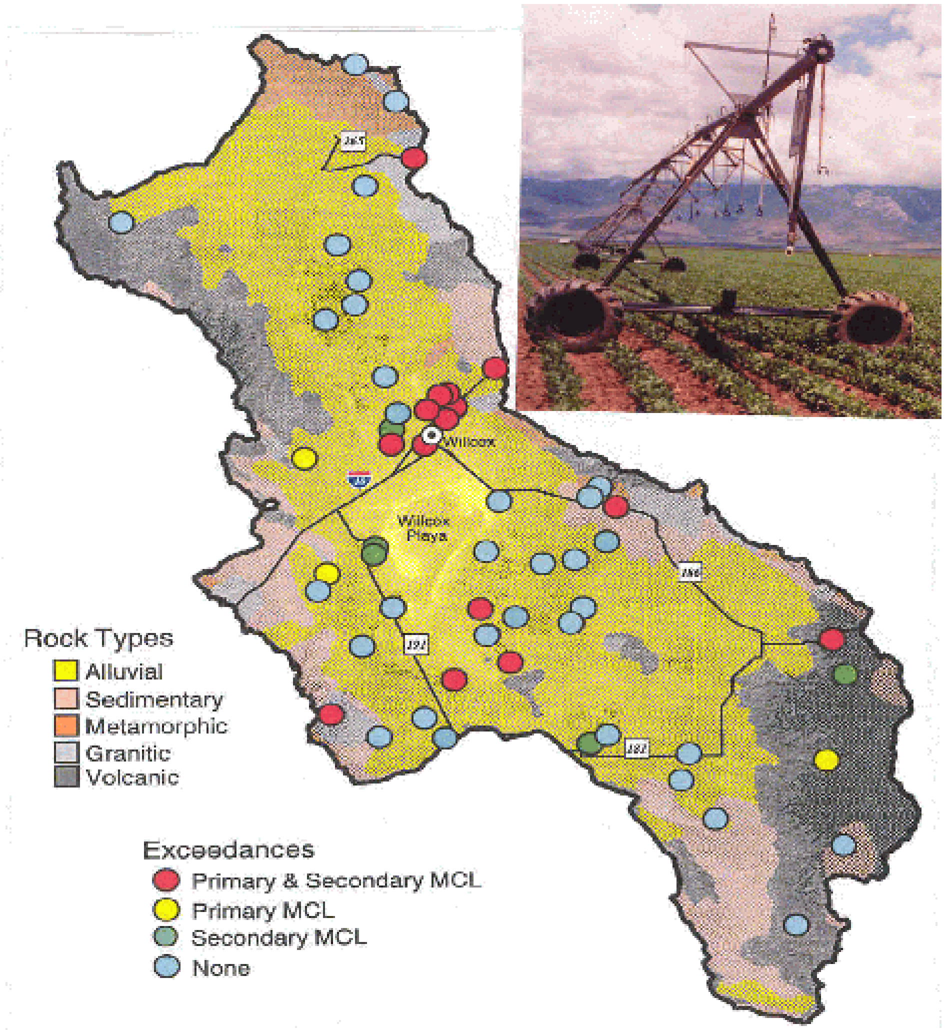

Figure 4. Locations of 58 sample sites are shown, including 21 sites exceeding health-based water quality standards and 23 sites exceeding aesthetics-based water quality guidelines. Inset photo shows a center-pivot irrigation unit in front of Mt. Graham and the Pinaleno Mountains.

from both unconsolidated alluvium (stream and lacustrine deposits) and the underlying consolidated alluvium. Aquifer materials in the Kansas Settlement District are more homogenous but much less permeable than the Stewart District[2]. *Hardrock* areas contain limited amounts of groundwater and are most productive in fractured bedrock and in thin alluvial deposits overlying the bedrock[2]. *Hardrock* areas are composed of granitic, metamorphic, sedimentary, and volcanic rock (**Figure 4**).

The majority of groundwater pumped in the WGB is for irrigation use; lesser amounts are withdrawn for municipal, domestic, stock, and other purposes. Groundwater generally flows from mountain fronts toward the Willcox Playa, though heavy irrigation pumping has partially altered this flow and created groundwater depressions in intensively farmed areas[3].

IV. Methods of Investigation

This study was conducted by the ADEQ Ambient Groundwater Monitoring Program, which is based on the legislative mandate in Arizona Revised Statutes §49-225. To characterize regional groundwater quality, 58 sites were sampled: 41 grid-based random sites and 17 targeted sites. Samples were collected at all sites for inorganic constituents. At selected sites, samples were also collected for Volatile Organic Compounds (VOCs)(54 sites), radiochemistry (44 sites), and pesticide (4 sites) analyses. Sampling protocol followed the *ADEQ Quality Assurance Project Plan*. Based on quality control data, the effects of sampling equipment and procedures on the results were not considered significant.

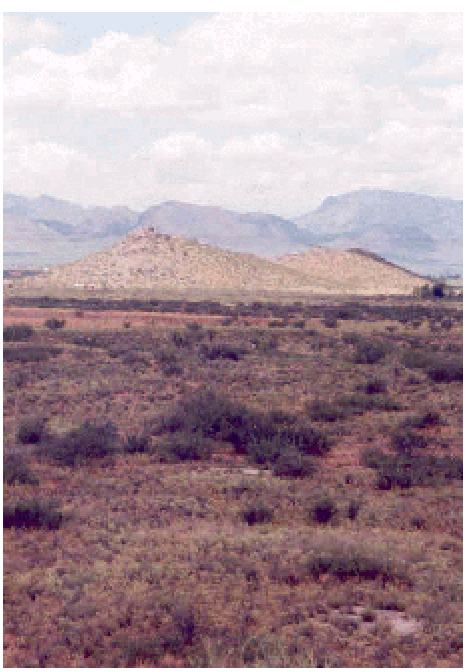

Figure 3. Elevated fluoride, arsenic, and pH levels are found near the Spike E Hills and may be associated with the Apache Pass fault.

V. Water Quality Sampling Results

The collected groundwater quality data were compared with Environmental Protection Agency (EPA) Safe Drinking Water (SDW) water quality standards. Primary Maximum Contaminant Levels (MCLs) are enforceable, health-based water quality standards that public systems must meet when supplying water to their customers. Primary MCLs are based on a lifetime daily consumption of two liters of water.

Of the 58 sites sampled, 21 had parameter levels exceeding a Primary MCL (**Figure 4**). Site exceedances included fluoride and gross alpha (eight apiece), nitrate (five), arsenic (three), and antimony and radium (one apiece).

EPA SDW Secondary MCLs are unenforceable, aesthetics-based water quality guidelines for public water systems. Water with Secondary MCL exceedances may be unpleasant to drink and/or create unwanted cosmetic or laundry effects but is not considered a health concern. Of the 58 sites sampled, 23 had parameter levels exceeding a Secondary MCL (**Figure 4**). Site exceedances included fluoride (13), total dissolved solids (TDS) (11), pH and sulfate (4 apiece), chloride (2), iron and manganese (1 apiece).

One site had four VOC detections that were common by-products of chlorination. None of the 152 pesticides or related degradation products on the ADEQ Groundwater List were detected.

> ***" An area of elevated fluoride, arsenic, and pH levels was found about 3.5 miles northeast of the city of Willcox centered around the Spike E Hills, a small metamorphic rock outcrop."***

VI. Groundwater Composition

In general, groundwater in the WGB is *slightly alkaline* (pH > 7 standard units) and *fresh* (TDS < 1000 milligrams per liter or mg/l). In the northern part of the basin, groundwater is particularly low in salts and minerals. TDS levels slowly increase from 46 mg/l at a spring atop Mt. Graham to levels still generally below 200 mg/l in the Stewart District.

Most sample sites exhibited a *calcium-bicarbonate* chemistry, though sodium was often the dominant cation near the playa. A cluster of *calcium-sulfate* sites was found near the Sulphur Hills. Sample sites were almost evenly divided among *soft*, *moderately hard*, *hard*, and *very hard* groundwater. Generally, *soft* water was found to the northeast and southeast of the playa while *very hard* water was found west of the playa.

Nitrate (as nitrogen) was found at 24 percent of sample sites at levels over 3 mg/l, which may indicate impacts from human activities. Although sites with elevated nitrate levels were scattered, many were located near Willcox and Kansas Settlement.

Boron, chromium, fluoride, and zinc were the only trace elements detected at more than ten percent of sites. Trace elements such as antimony, arsenic, barium, beryllium, cadmium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, and thallium were rarely detected.

VII. Groundwater Evolution

Two distinct groundwater evolution patterns occurred in the WGB. To the north in the Stewart District, recharge occurs primarily from the Pinaleno Mountains. In a flowpath stretching from Mt. Graham to the Willcox Playa, groundwater is typically a *calcium-bicarbonate* type gradually evolving into a *sodium-mixed anion* chemistry near the playa. This pattern is typical of a *closed hydrologic system* in which the aqueous chemistry is determined solely by reactions of the initial recharge water with minerals as it flows downgradient[4].

To the south, in the Kansas Settlement District, recharge primarily occurs from the Chiricahua Mountains. In a flowpath stretching along Turkey Creek, groundwater evolves from a *calcium-bicarbonate* into *sodium-bicarbonate* near the Sulphur Hills, and finally into *calcium-sulfate* near the playa. Calcium and bicarbonate increase while chloride, pH, sodium, and sulfate decrease at points along this flowpath. This indicates an *open hydrologic system* in which groundwater chemistry is in part controlled or influenced by atmospheric gases or liquids that enter the system subsequent to initial recharge[4].

VIII. Groundwater Quality Patterns

Nitrate, pH, potassium, and temperature levels were higher in the *alluvial aquifer* than in *hardrock* areas. Chloride, pH, and sodium levels were higher in the young alluvium near the Willcox Playa than in the old alluvium. Gross alpha levels (**Figure 5**) were higher in granitic rock than in young or old alluvium (Kruskal-Wallis and Tukey test, p # 0.05).

Bicarbonate, calcium, hardness, sulfate, and total alkalinity levels were significantly higher in the southern portion of the WGB than in the northern portion (Kruskal-Wallis test, p # 0.05).

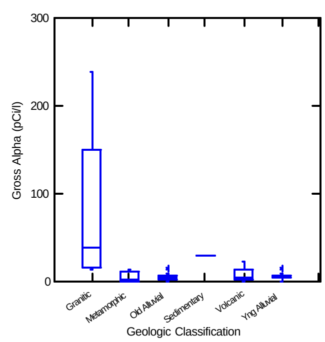

Figure 5. Gross alpha levels are higher in granitic rock than in either old or young alluvium (Kruskal-Wallis test, p # 0.05).

Temperature, pH, and zinc levels increased with increasing groundwater depth below land surface (bls). In contrast, bicarbonate, calcium, chloride, gross alpha, hardness, sodium, specific conductivity, sulfate, TDS, and total Kjeldahl nitrogen (TKN) levels decreased with increasing groundwater depth bls (regression analysis, p # 0.05).

Many of these parameters, especially major ions, show a similar pattern to TDS (**Figure 7**) which attains a *critical level* at approximately 110 feet bls. TDS levels remain generally constant at groundwater depths greater than the *critical level* and are highly variable at more shallow depths.

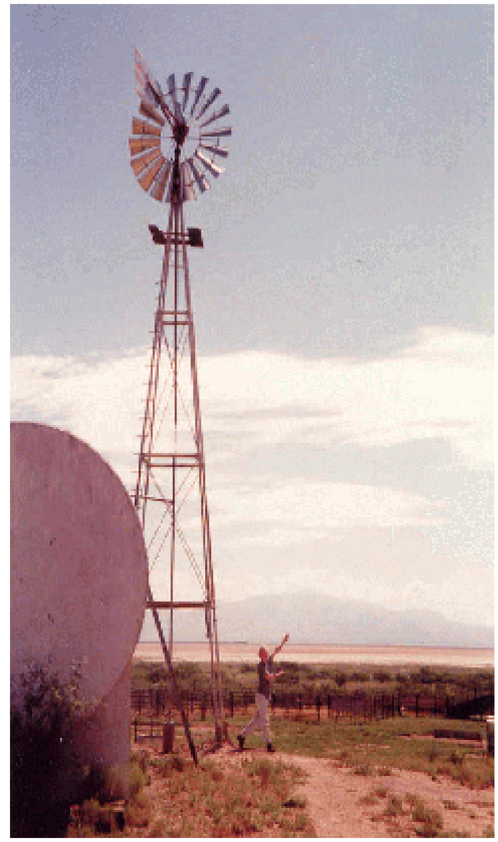

Figure 6. A windmill, the Dos Cabezas Mountains, and an ADEQ hydrologist rise above the WGB's low point, the Willcox Playa.

IX. Targeted Sampling Results

Additional sampling was conducted three miles northeast of the city of Willcox near the Spike E Hills, a small metamorphic rock outcrop just downgradient of the Apache Pass fault. These sites had *soft*, *alkaline*, *sodium-mixed anion* groundwater that often exceeded arsenic standards. Fluoride levels often exceeded the 4 mg/l Primary MCL for fluoride, with levels reaching 10 mg/l (**Figure 8**).

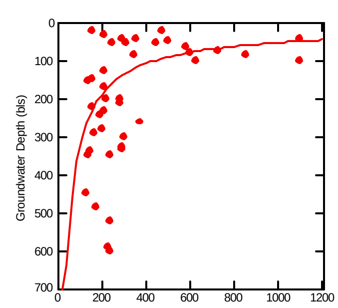

Figure 7. TDS generally decreases with increasing groundwater depth below land surface (regression analysis, p# 0.05).

Fluoride levels are controlled by three factors: the availability of fluoride ions in the alluvium and/or rock, calcium levels, and hydroxyl ion exchange[4]. Fluoride sources in the area include lacustrine deposits and volcanic rocks[3]. Calcium is an important control of higher fluoride levels (>5 mg/l) through precipitation of the mineral fluorite (CaF_2). In a *closed hydrologic system*, calcium is removed from solution by calcium carbonate precipitation and formation of smectite clays[4].

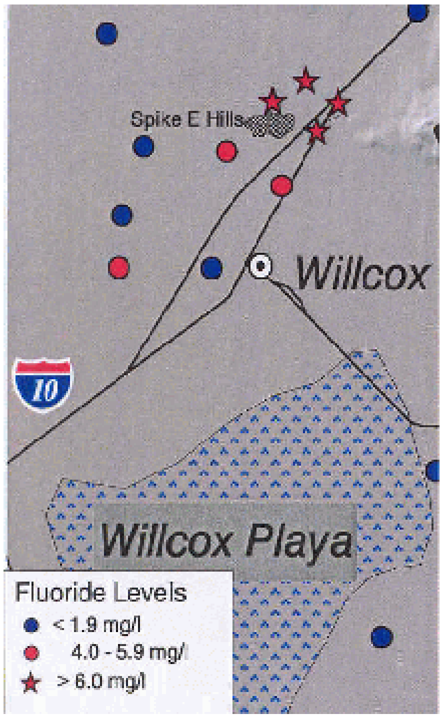

Figure 8. Elevated fluoride found near Willcox might be related to the Apache Pass fault producing water from great depths.

Additional sampling was also conducted in the Kansas Settlement District to examine for parameter level variations with groundwater depth. Wells were divided into two groups using the 110 foot *critical groundwater level*. TDS, chloride, magnesium, sodium, and TKN levels were higher in wells with shallow groundwater compared to those with deep groundwater (Kruskal-Wallis test, p # 0.05). Nitrate levels exceeded the Primary MCL in three shallow wells. These patterns are most likely caused by irrigation recharge containing nitrate and salts, concentrated by evaporation.

"Groundwater radiochemistry levels are highest in granitic rock, particularly in areas of mining activity. These levels often exceed water quality standards."

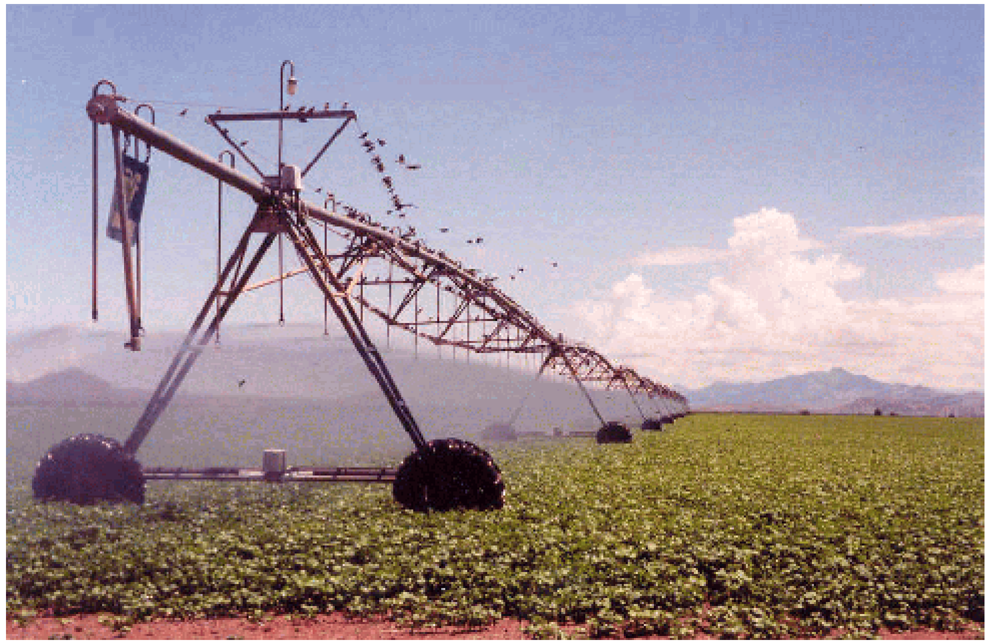

Figure 9. Birds flock to the spray of a center-pivot irrigating a cotton field in the Stewart District. The Dos Cabezas Mountains and afternoon thunderstorms loom on the horizon.

X. Study Conclusions

Since one-third of sample sites in the WGB did not meet water quality standards, ADEQ suggests that well owners periodically have their groundwater analyzed by certified laboratories. Well owners should be particularly concerned about elevated parameter levels in the following portions of the basin where water quality exceedances were concentrated:

- Fluoride, arsenic, and pH near the Spike E Hills northeast of Willcox;.
- Gross alpha in areas of granitic rock throughout the basin;
- Nitrate, fluoride, and sulfate northwest of the Sulphur Hills; and
- Chloride and sulfate west of the Willcox Playa.

The other water quality exceedances occurred at scattered sites and may not reflect groundwater quality conditions prevalent over large areas of the basin. These results suggest that in other parts of the WGB, groundwater appears to be largely suitable for domestic purposes.

Although only limited time-trend analyses were conducted for this study, parameters in most areas of the basin appear to be controlled by natural geochemical reactions and would probably not vary significantly with time in the short term. The Kansas Settlement District may be an exception to this statement. Trends in this area indicate that groundwater quality seems to be influenced by nitrate and salts carried by excess irrigation water that percolates downward, ultimately recharging the groundwater.

---Douglas Towne and Maureen Freark
Maps by Larry W. Stephenson
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References Cited

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2. Brown, S.G. and Schumann, H.H., 1969. *Geohydrology and Water Utilization in the Willcox Basin, Graham and Cochise Counties, Arizona.* USGS Water-Supply Paper 1859-F.
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4. Robertson, F.N., 1986. "Occurrence and Solubility Controls of Trace Elements in Groundwater in Alluvial Basins of Arizona" in Anderson, T.W. and Johnson, A.I., eds., *Regional Aquifer Systems of the United States, Southwest Alluvial Basins of Arizona.* American Water Resources Association Series #7.

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